# Comparisons of in-situ snow depth measurements with airborne data

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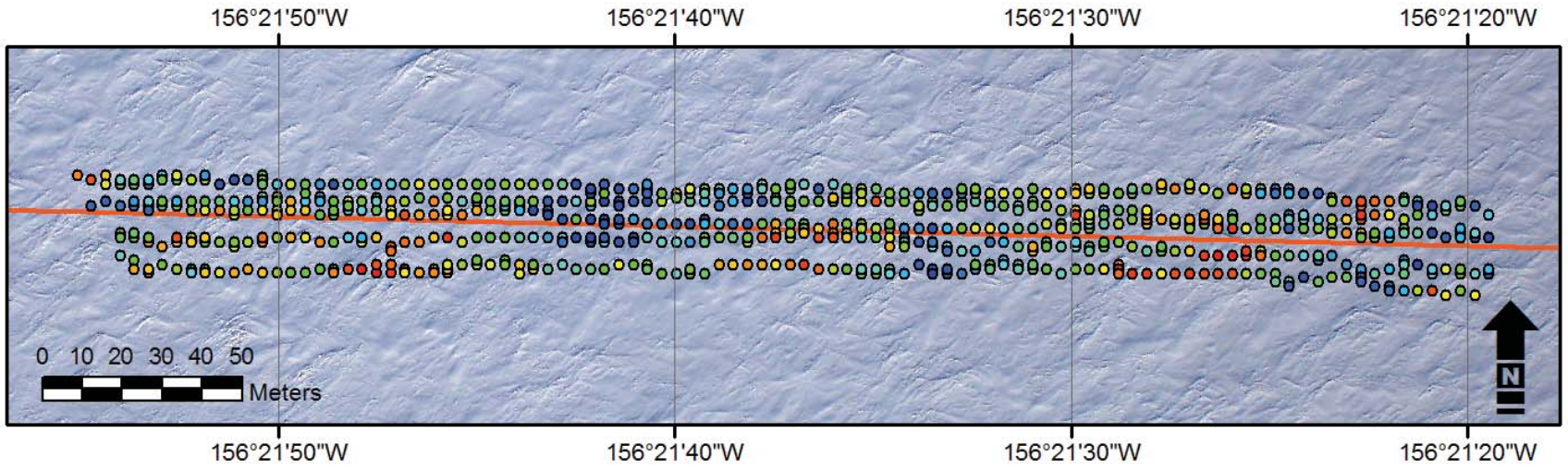
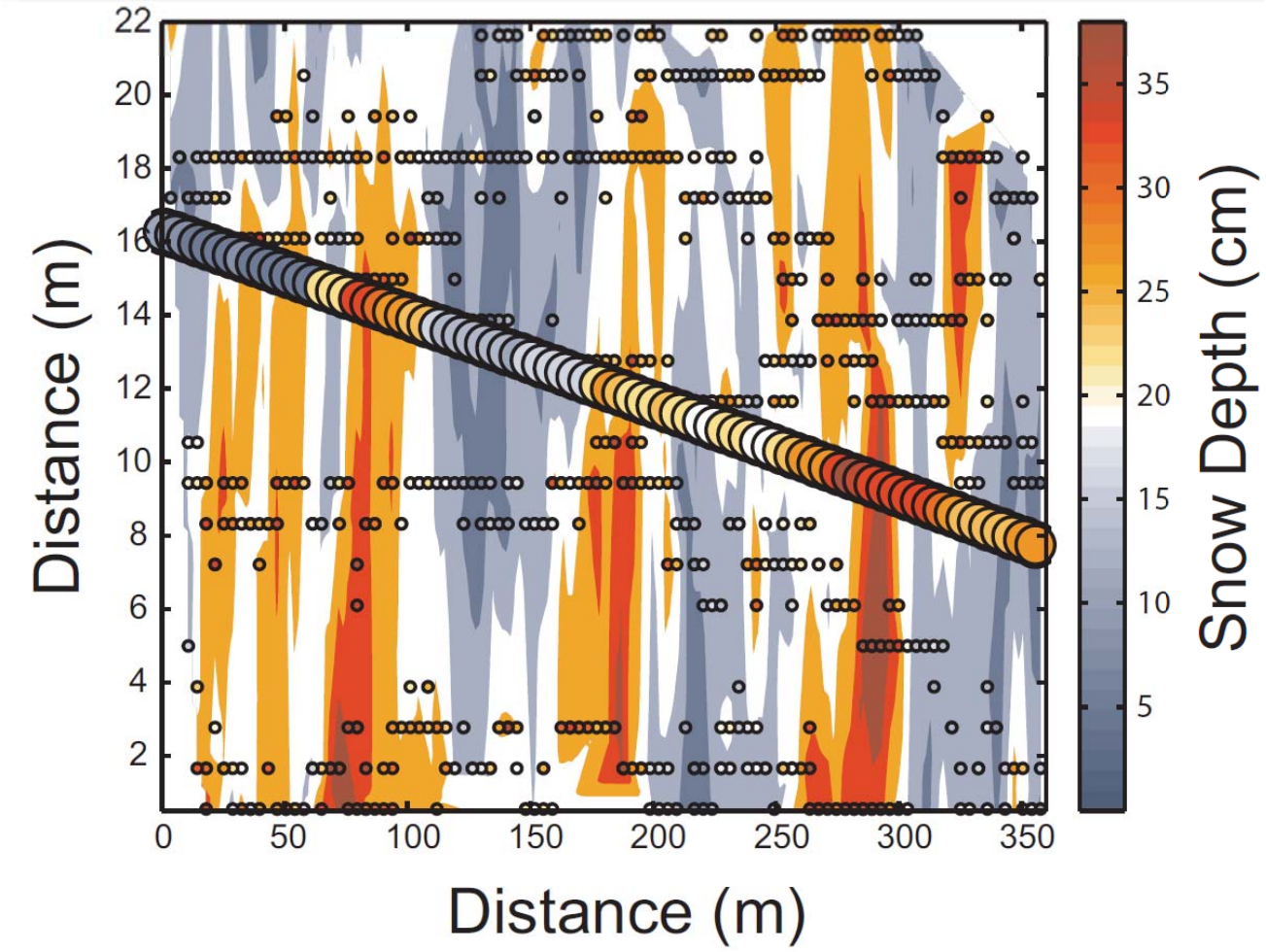



Webster et al., JGR, 2014

# Comparing in-situ measurements with airborne measurements: where are we?

- How well do existing ground measurements characterize snow depth for comparisons with airborne data?
- Are existing in-situ sampling strategies suitable for comparisons in terms of spatial sampling, measuring parameters and statistics?
- What is the statistical significance of existing in-situ and airborne data comparisons?
- What do we need to do to the design experiments that are likely to provide definite answers?

# Existing in-situ/EM/airborne data sets

| Year | Area | Organizations/PI | Experiment | Data Availability | Publication |
|---|---|---|---|---|---|
| 2009 | Fast ice north of Cape Morris Jesup | CRREL, DTU Space | GreenArc | no | yes |
| 2011 | Beaufort Sea | NRL, CRREL | ICEX 2011 | published on 9/15/2014 at NSIDC | submitted |
| 2011 | North of Alert | ESA, UCL, York Univ | CryoVEx | ESA (no 20 m grids) | no |
| 2012 | Barrow, AK Elson Lagoon | JPL, CRREL, UW APL | BROMEX | on request | yes |
| 2012 | North of Alert | ESA, DTU Space, York U | CryoVEx – no ground data | ESA | no |
| 2012 | Fram Strait | ESA, DTU Space, York U | CryoVEx – no ground data | ESA | no |
| 2012 | Qaanaaq Fjord, Greenland | J Wilkinson (SAMS), S Hanson (DMI), P Elosegui (ICE), H Singh, P Kimball (WHOI) | Qaanaaq Sea Ice Field Campaign | no | no |
| 2013 | Barrow, AK | UW APL, NRL, U Delaware | NRL/BROMEX/AOX/ NAICEX/MERLIN | no | no |
| 2014 | Barrow, AK | CRREL, NRL | NRL DISTANCE | no | |
| 2014 | Canada Basin | CRREL, ONR, NRL, ESA, York University | ONR MIZ, CryoVEx | no | |
| 2014 | North of Alert | ESA, DTU Space, York U | CryoVEx – no ground data | no | |
| 2014 | Cape Morris Jesup | ESA, York University | CryoVEx | no | |
| 2014 | Eureka Sound | Environment Canada | In support for NASA/CSA agreement | will be | |

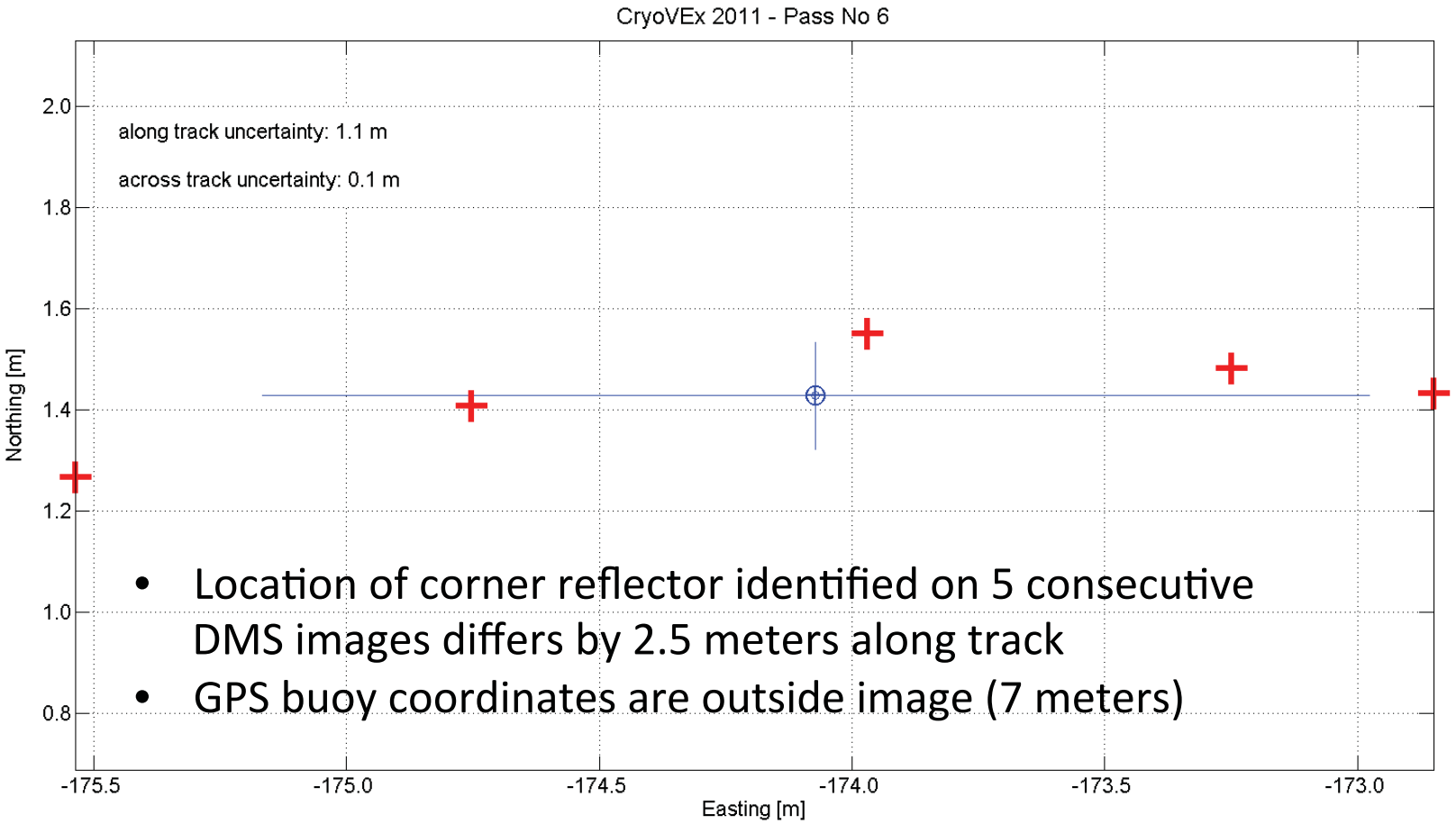
Note: airborne data have been acquired at significant cost/flight hours for IceBridge.

# Challenges

- Logistics and costs involved in obtaining in-situ data
- “Only” opportunistic coordination so far.
  No dedicated experiments that were specifically designed to provide answers once and for all.
- Very small in-situ survey areas (statistical significance?)
- Profile data often don’t even span or barely exceed the width of the radar cross-track footprint
  (2014 data are a significant improvement in this regard)
- High resolution grids barely cover the along-track and across-track size of the radar footprint
- Radar speckle and small in-situ area limit significance

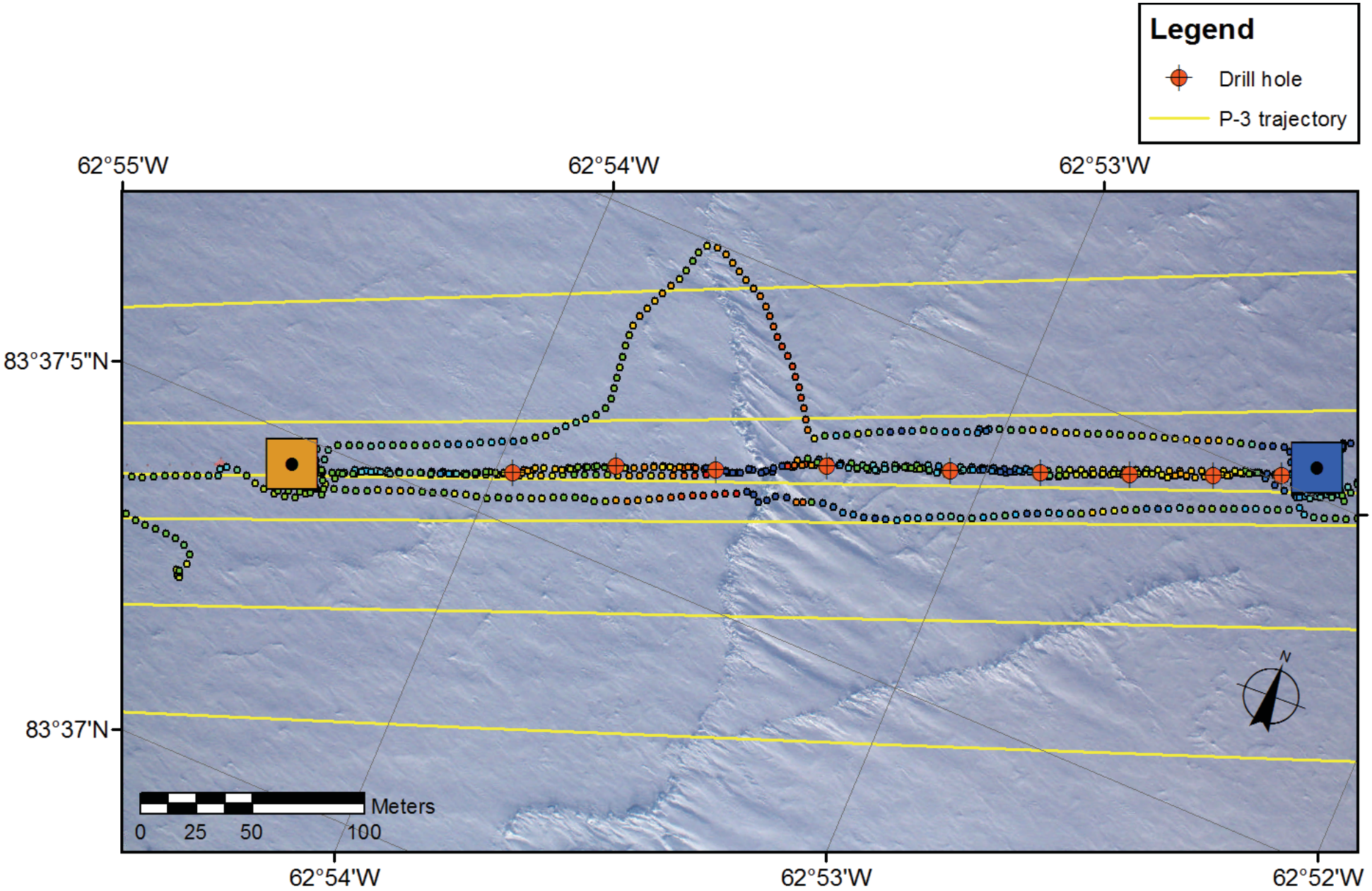
# Challenges – cont.

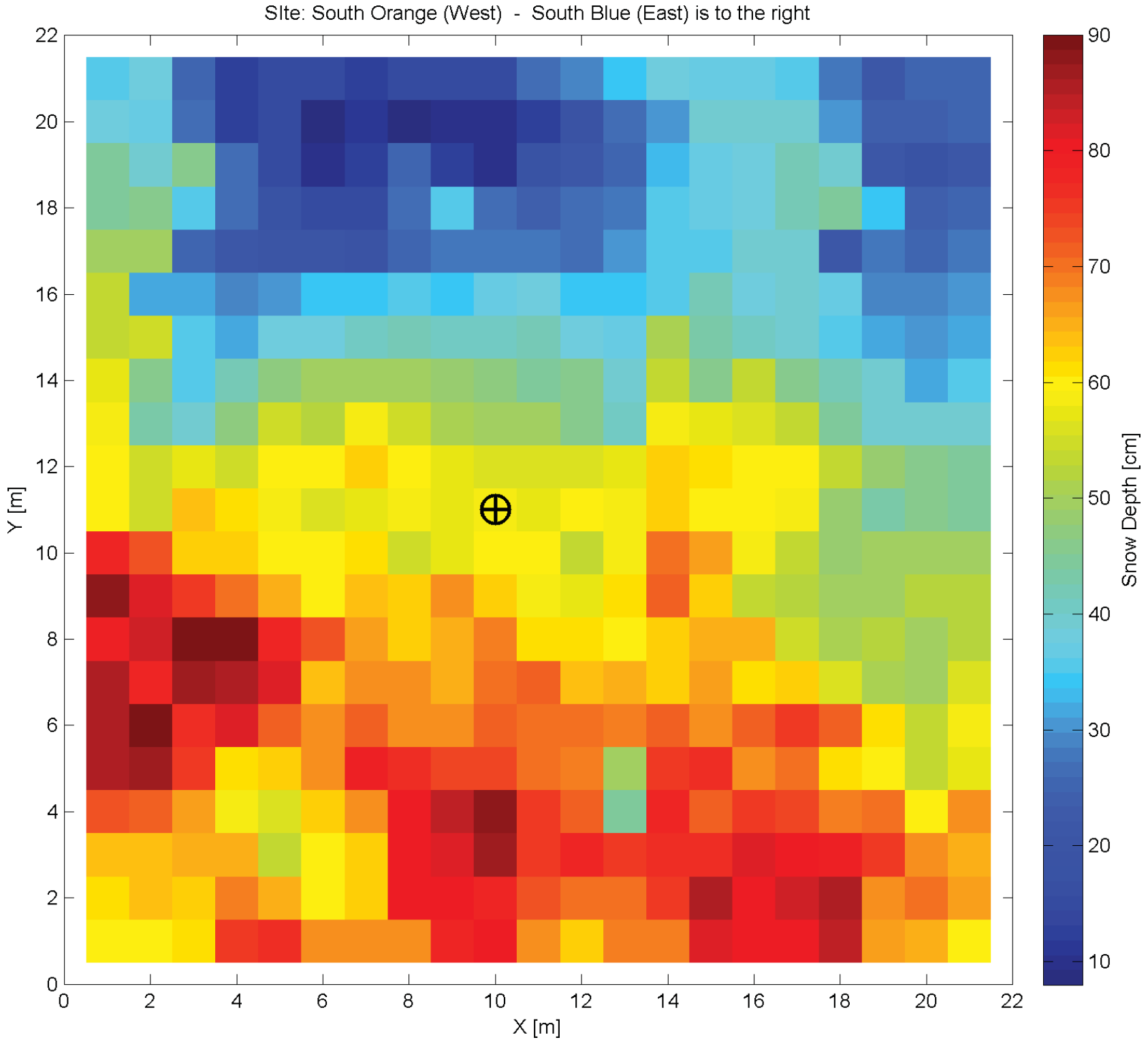
- Targets are moving with up to 200 meters/hour
- Co-locating high-resolution grids and corner reflectors with airborne measurements is a challenge.
- Geodetic quality dual frequency post-processed DGPS or PPP?

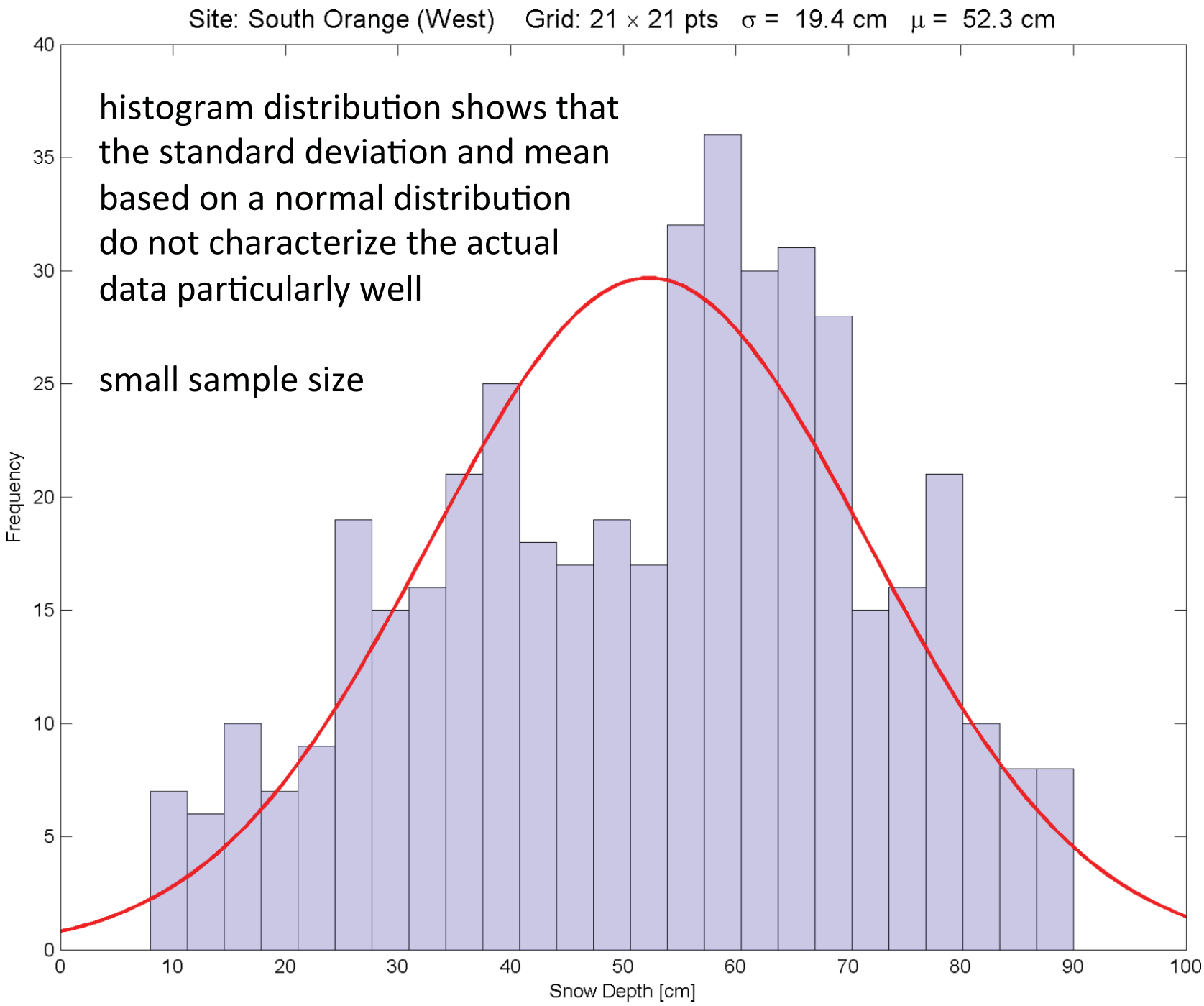



- Location of corner reflector identified on 5 consecutive DMS images differs by 2.5 meters along track
- GPS buoy coordinates are outside image (7 meters)

# April 15, 2011: the “golden day”

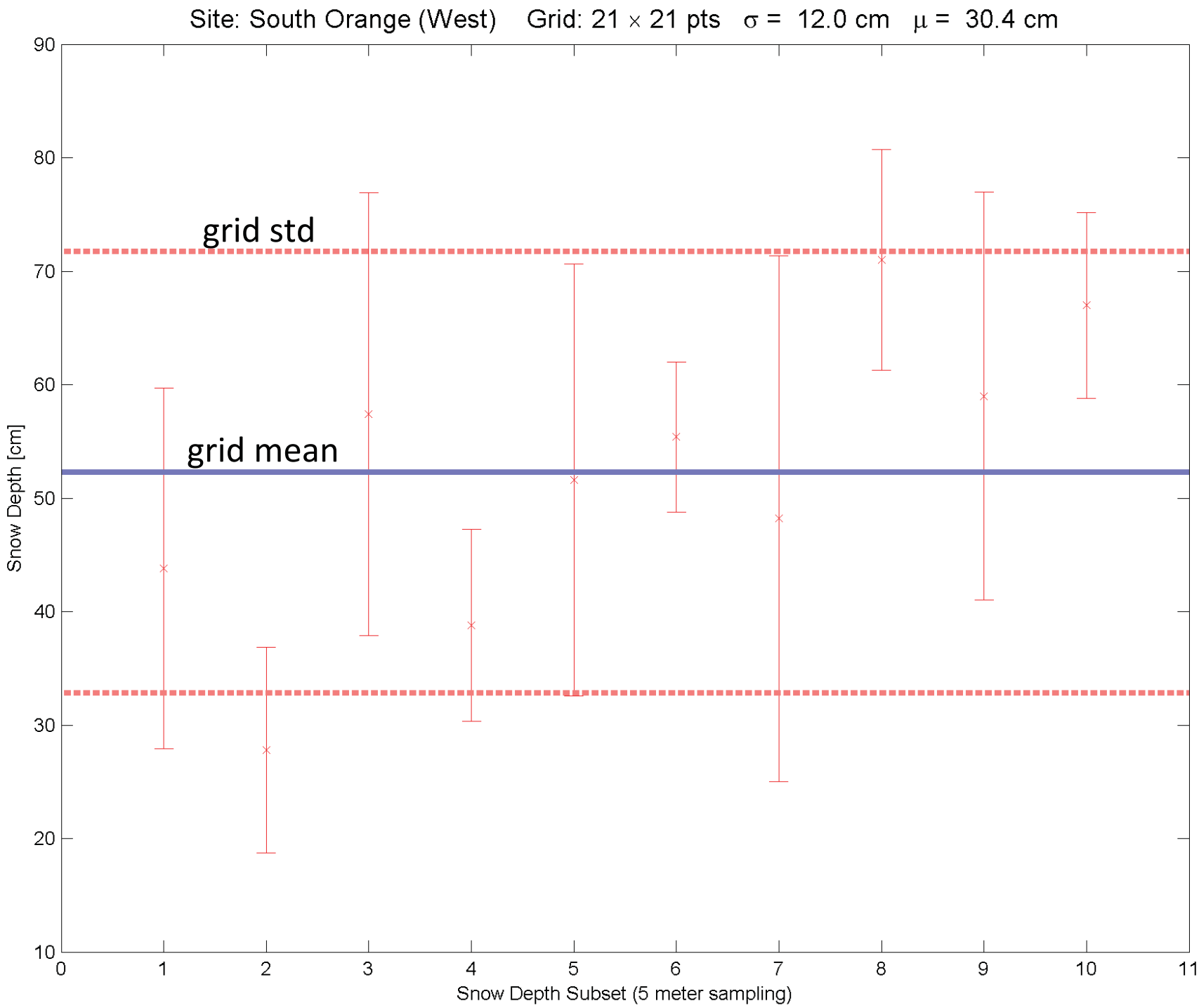


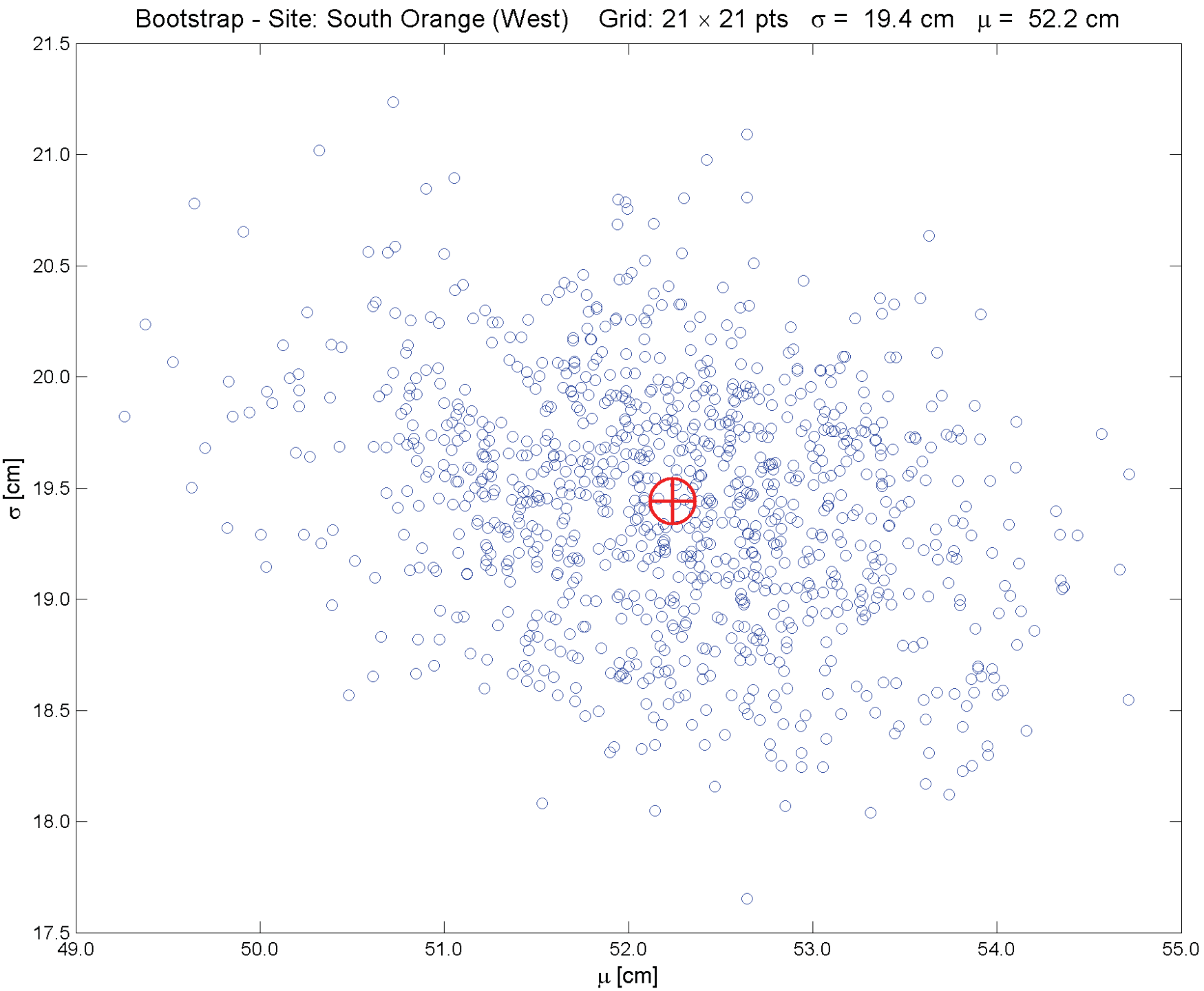

SIte: South Orange (West) - South Blue (East) is to the right
Y [m]
X [m]
Snow Depth [cm]
0
2
4
6
8
10
12
14
16
18
20
22
10
20
30
40
50
60
70
80
90

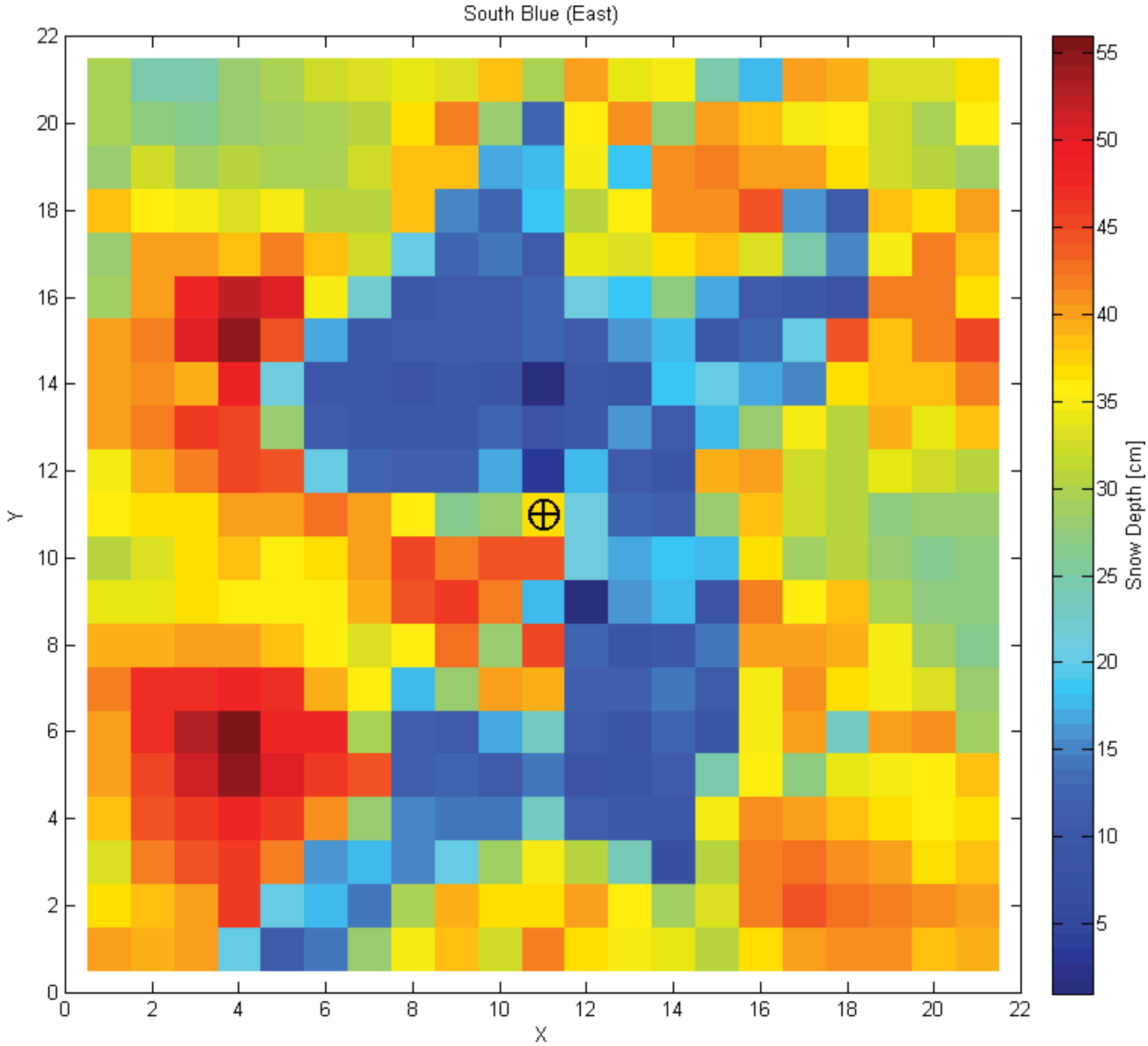

Site: South Orange (West) Grid: 21 × 21 pts σ = 19.4 cm μ = 52.3 cm
histogram distribution shows that the standard deviation and mean based on a normal distribution do not characterize the actual data particularly well
small sample size
Frequency
Snow Depth [cm]
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
80
90
100

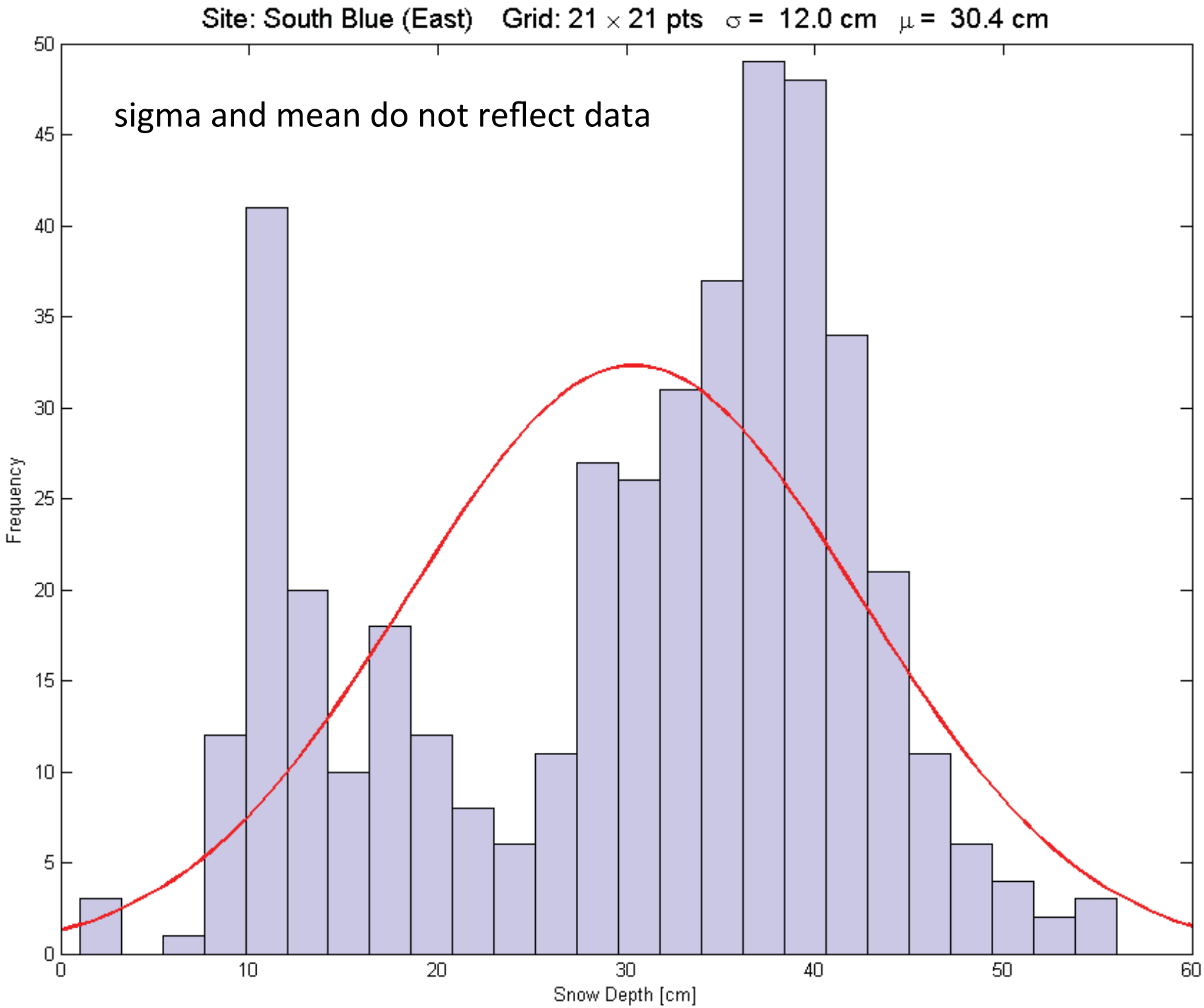
# Subsampling Experiments

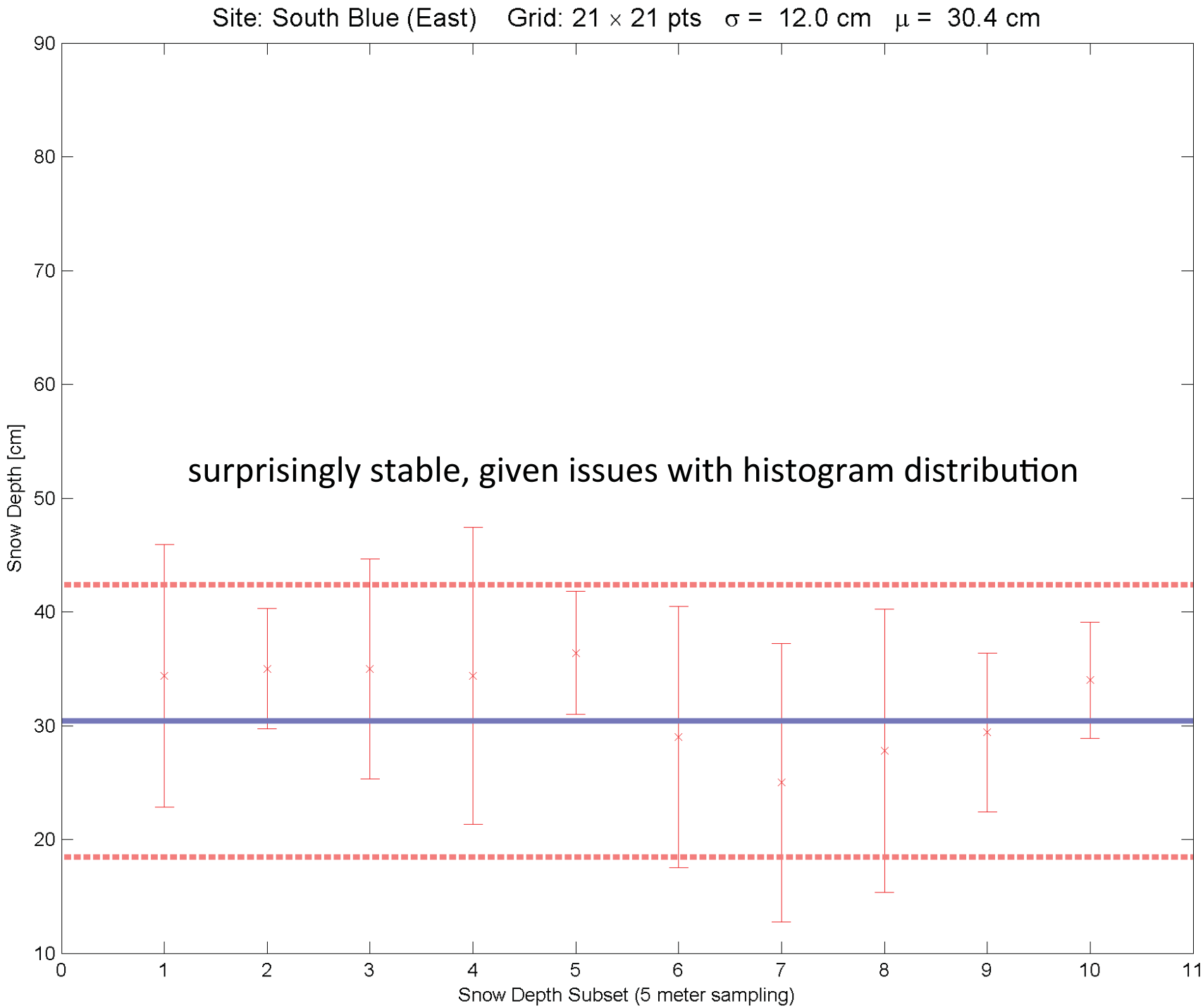
- simulate 5 meter profile measurements using subsamples from 20 meter high-resolution grids spaced 5 meters apart:
  how well can we characterize snow depths along profiles using 5 meter spacing?
- subsample grids using bootstrapping method with 1000 subsets

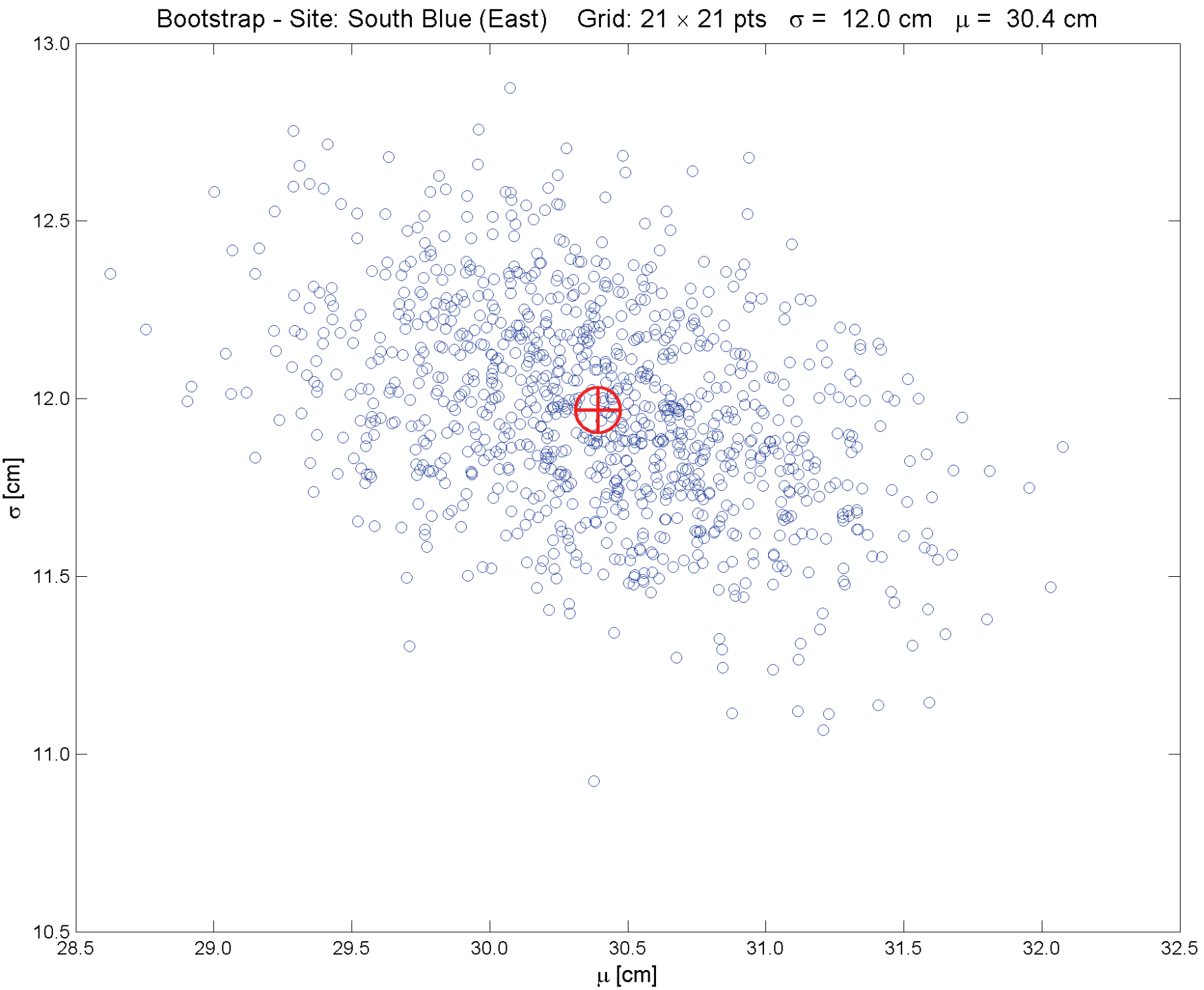

Site: South Orange (West) Grid: 21 × 21 pts σ = 12.0 cm μ = 30.4 cm
grid std
grid mean
Snow Depth [cm]
Snow Depth Subset (5 meter sampling)
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11

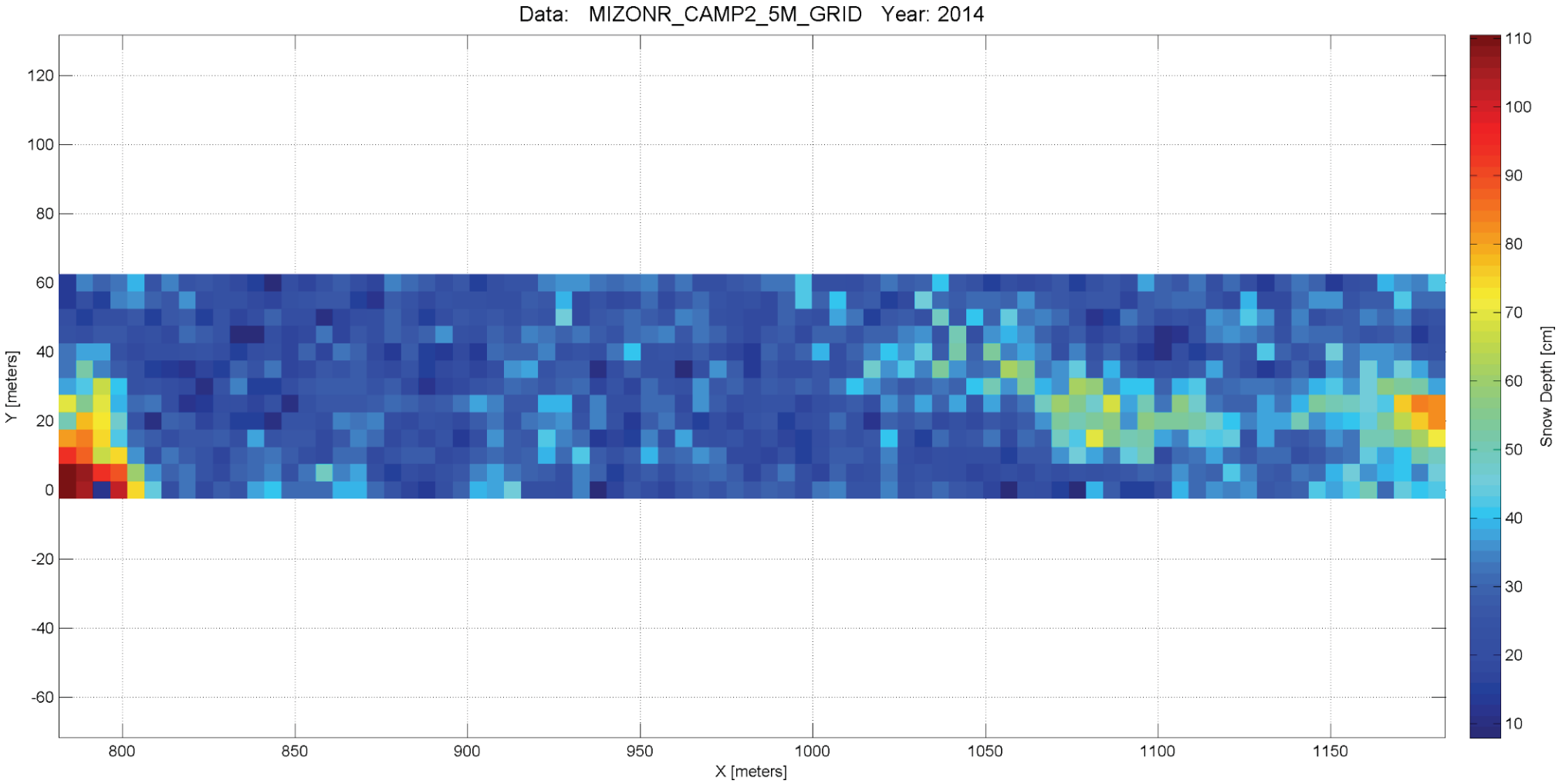

Bootstrap - Site: South Orange (West) Grid: 21 × 21 pts σ = 19.4 cm μ = 52.2 cm
21.5
21.0
20.5
20.0
19.5
19.0
18.5
18.0
17.5
σ [cm]
49.0
50.0
51.0
52.0
53.0
54.0
55.0
μ [cm]

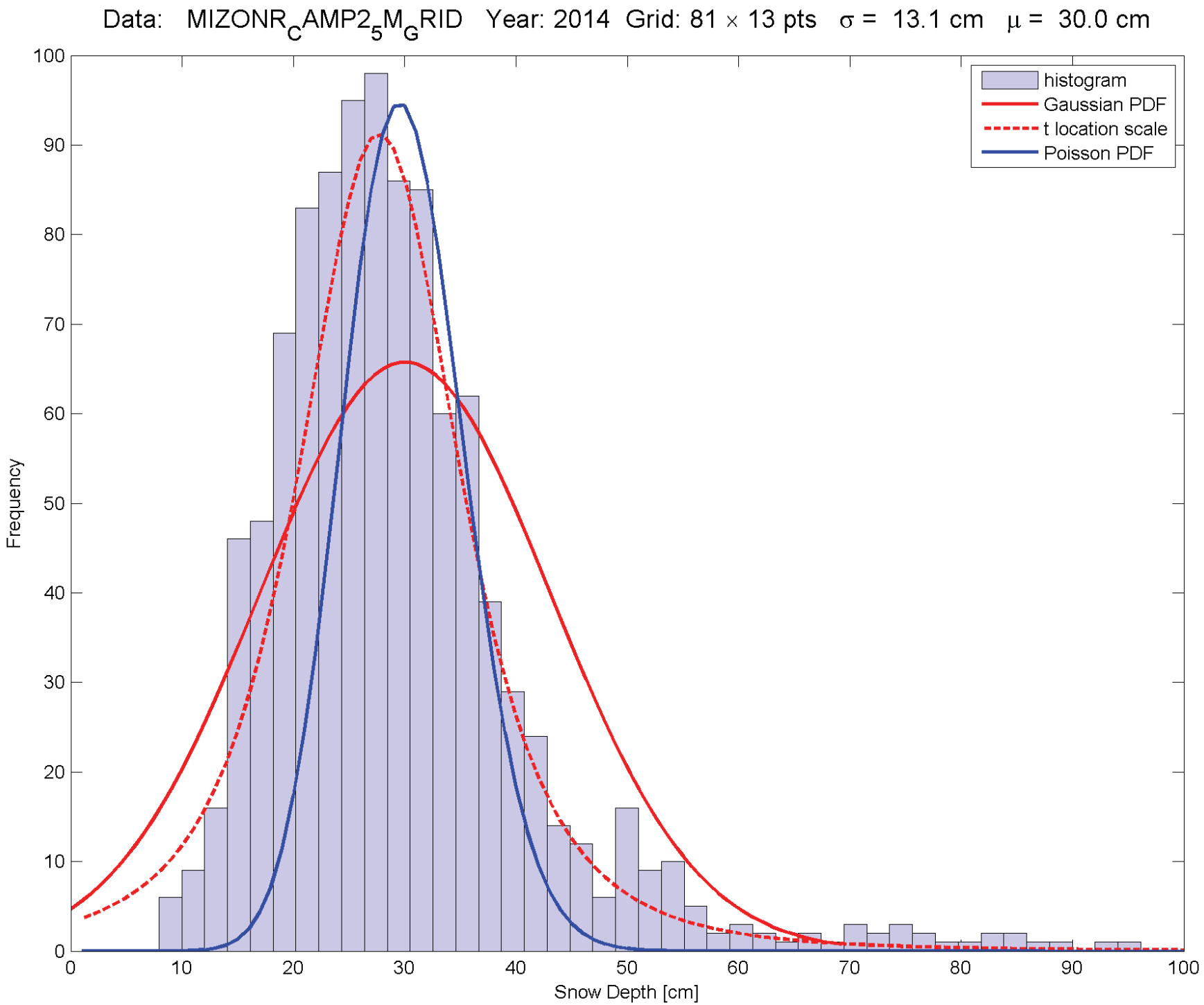

South Blue (East)
Y
X
Snow Depth [cm]
0
2
4
6
8
10
12
14
16
18
20
22
5
10
15
20
25
30
35
40
45
50
55

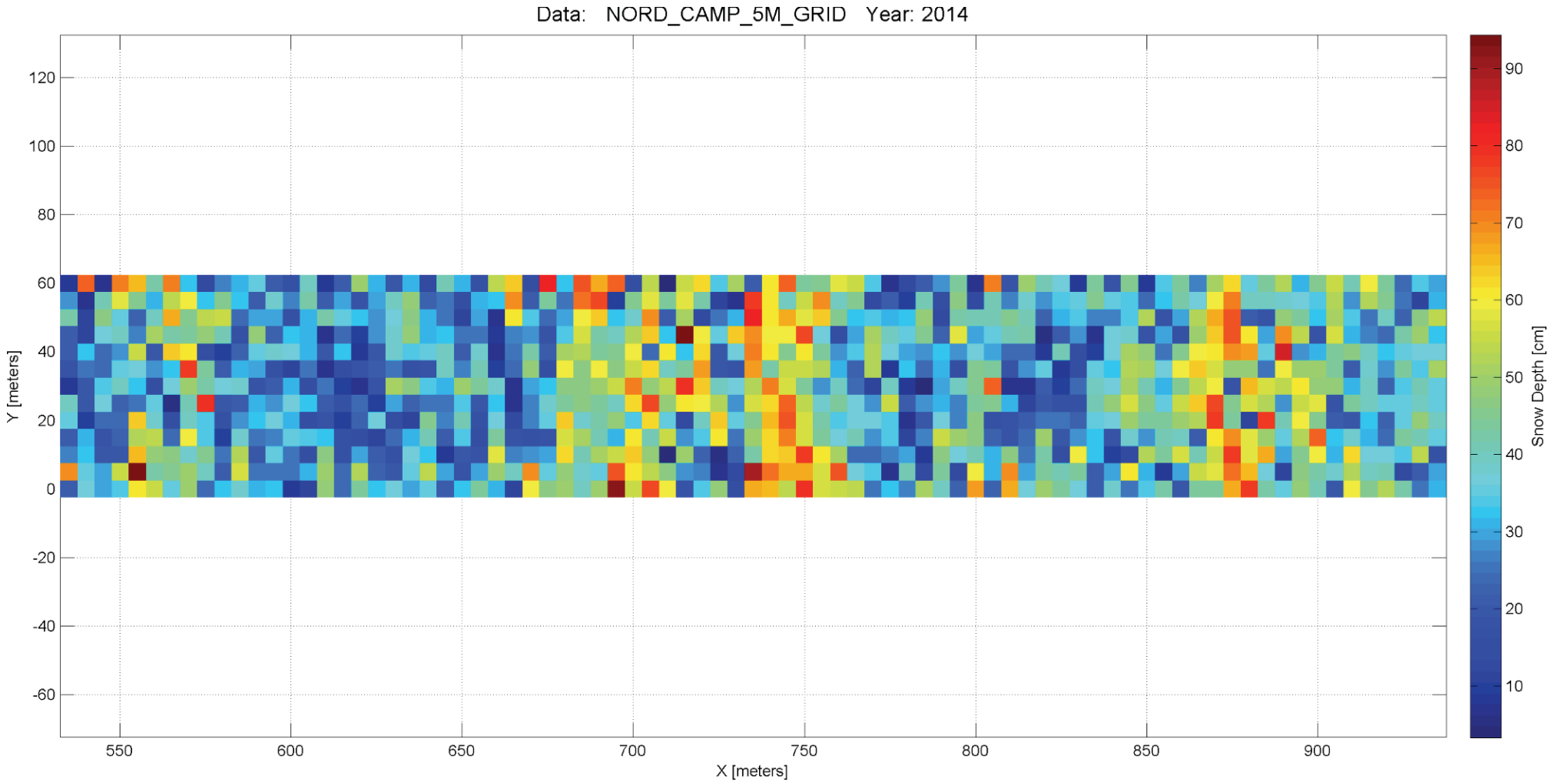

Site: South Blue (East) Grid: 21 × 21 pts σ = 12.0 cm μ = 30.4 cm
sigma and mean do not reflect data
Frequency
Snow Depth [cm]
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50
60

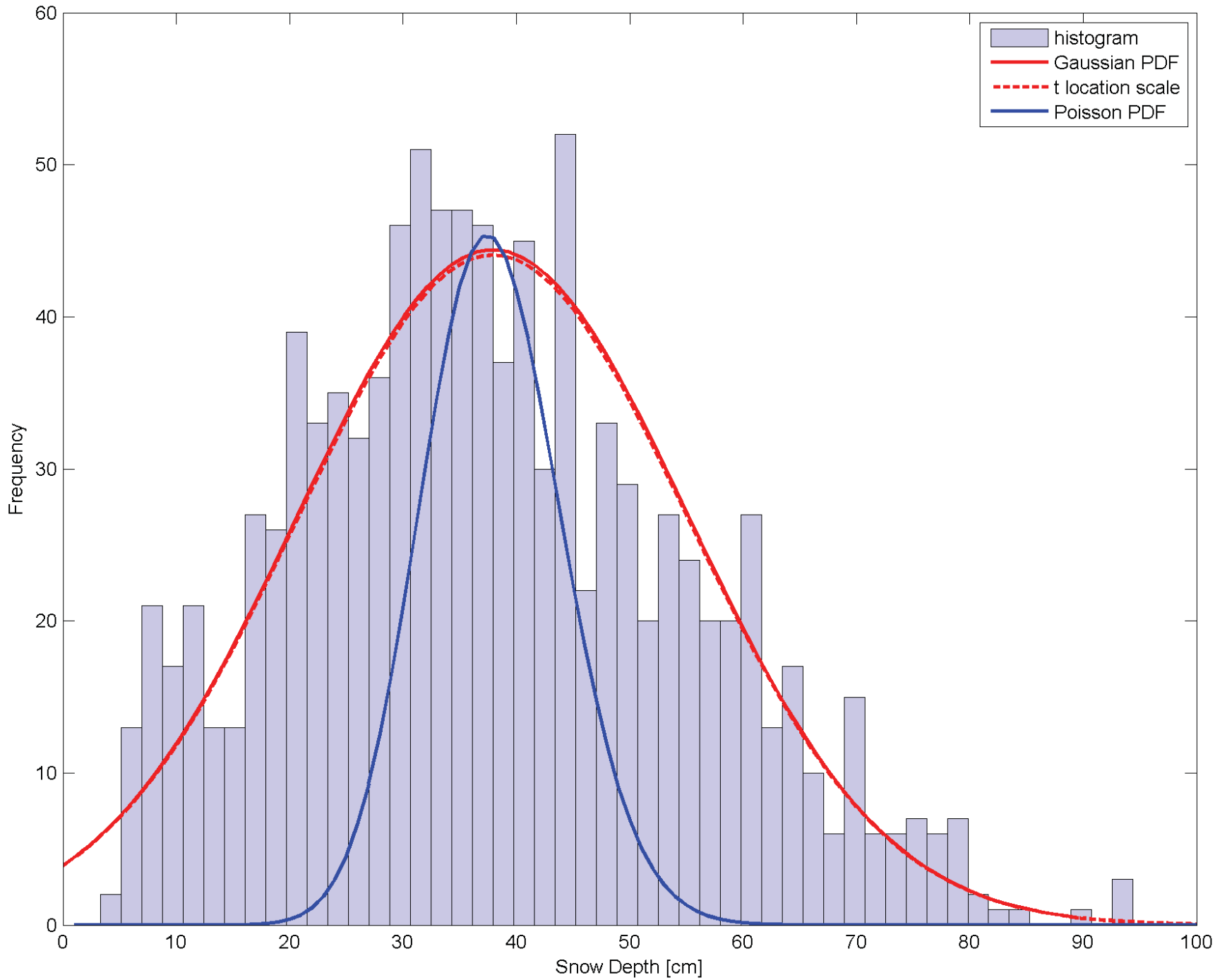

Site: South Blue (East) Grid: 21 × 21 pts σ = 12.0 cm μ = 30.4 cm
surprisingly stable, given issues with histogram distribution
Snow Depth [cm]
Snow Depth Subset (5 meter sampling)
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11

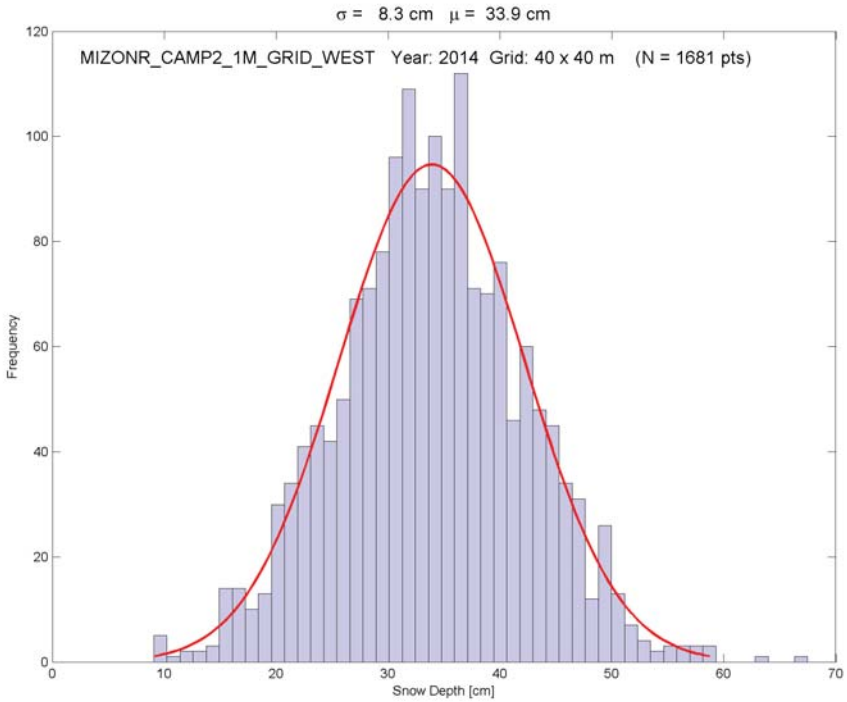

Bootstrap - Site: South Blue (East) Grid: 21 × 21 pts σ = 12.0 cm μ = 30.4 cm
13.0
12.5
12.0
11.5
11.0
10.5
σ [cm]
28.5
29.0
29.5
30.0
30.5
31.0
31.5
32.0
32.5
μ [cm]

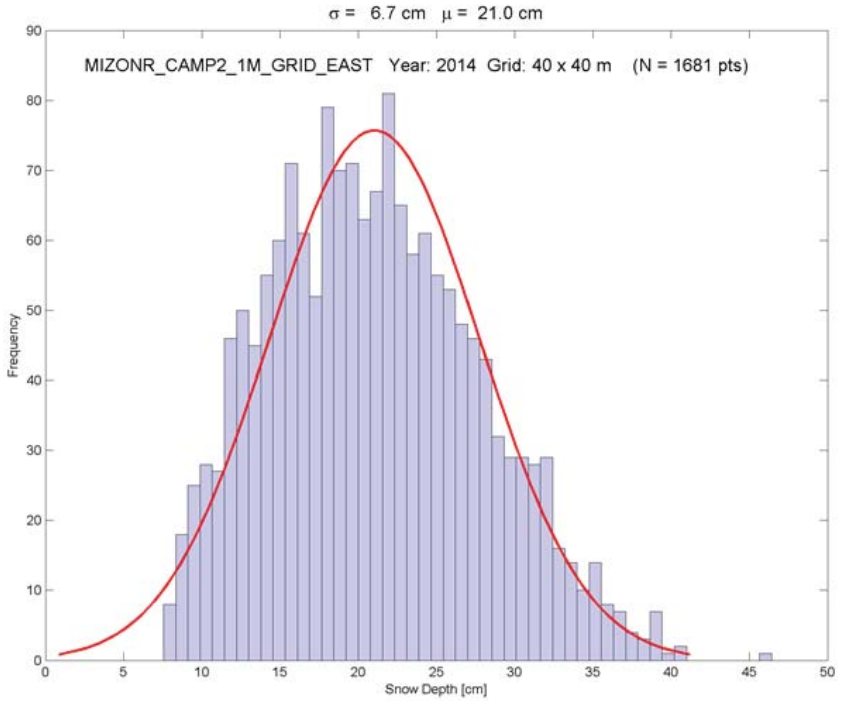

Data: MIZONR_CAMP2_5M_GRID Year: 2014
Y [meters]
120
100
80
60
40
20
0
-20
-40
-60
800
850
900
950
1000
1050
1100
1150
X [meters]
Snow Depth [cm]
110
100
90
80
70
60
50
40
30
20
10

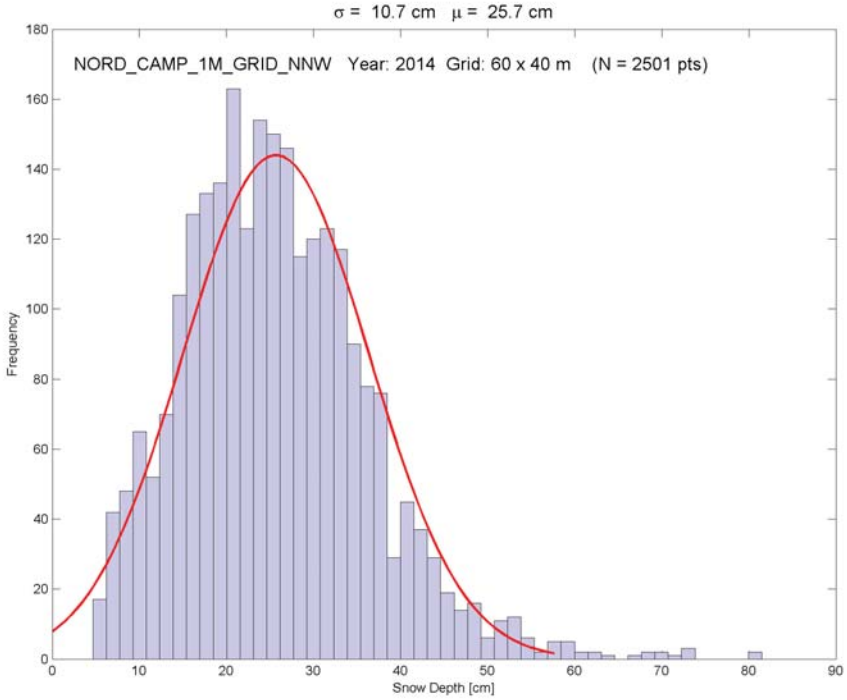

Data: MIZONR_C AMP2_5 M_G RID Year: 2014 Grid: 81 × 13 pts σ = 13.1 cm μ = 30.0 cm
histogram
Gaussian PDF
t location scale
Poisson PDF
Frequency
Snow Depth [cm]
0
10
20
30
40
50
60
70
80
90
100

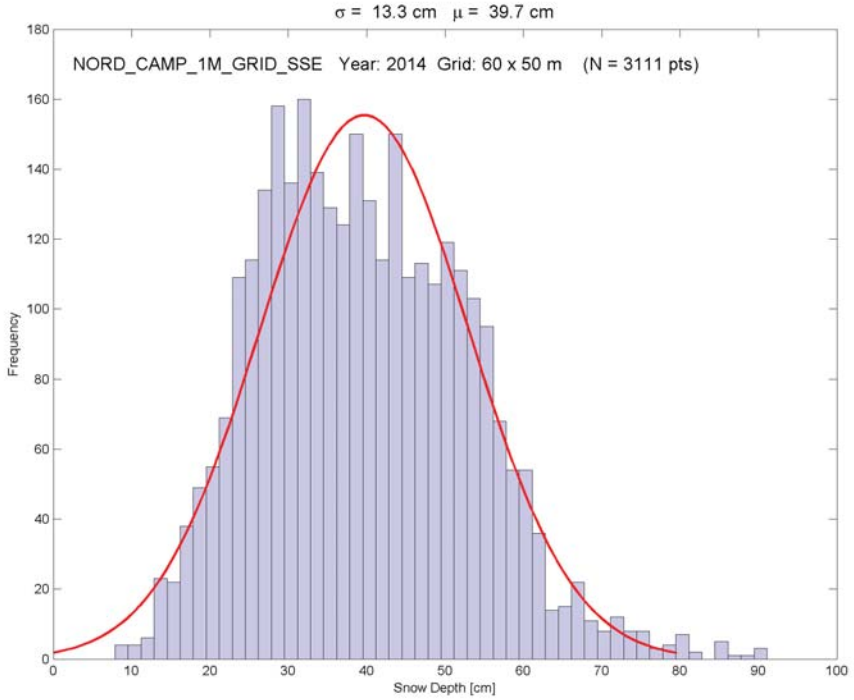

Data: NORD_CAMP_5M_GRID Year: 2014
Y [meters]
120
100
80
60
40
20
0
-20
-40
-60
550
600
650
700
750
800
850
900
X [meters]
Snow Depth [cm]
90
80
70
60
50
40
30
20
10


Data: NORD_CAMP_5M_GRID Year: 2014 Grid: 81 × 13 pts σ = 17.2 cm μ = 37.9 cm
histogram
Gaussian PDF
t location scale
Poisson PDF
Frequency
Snow Depth [cm]
0
10
20
30
40
50
60
70
80
90
100


σ = 8.3 cm μ = 33.9 cm
MIZONR_CAMP2_1M_GRID_WEST Year: 2014 Grid: 40 x 40 m (N = 1681 pts)
Frequency
Snow Depth [cm]


σ = 6.7 cm μ = 21.0 cm
MIZONR_CAMP2_1M_GRID_EAST Year: 2014 Grid: 40 x 40 m (N = 1681 pts)
Frequency
Snow Depth [cm]

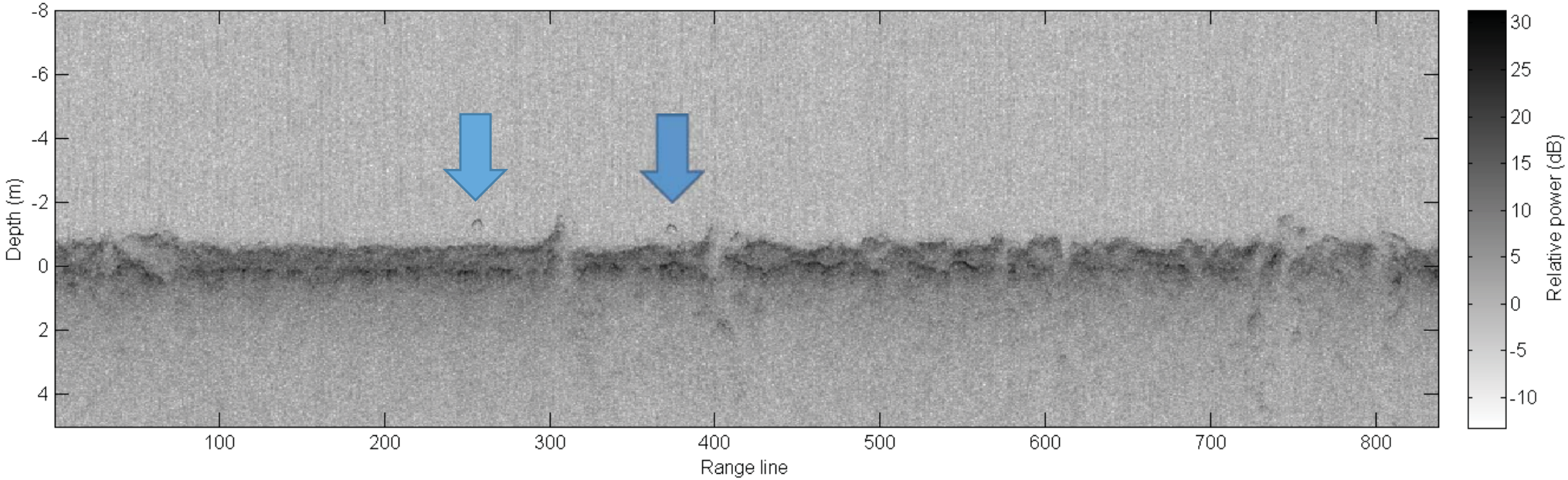

σ = 10.7 cm μ = 25.7 cm
NORD_CAMP_1M_GRID_NNW Year: 2014 Grid: 60 x 40 m (N = 2501 pts)
Frequency
Snow Depth [cm]

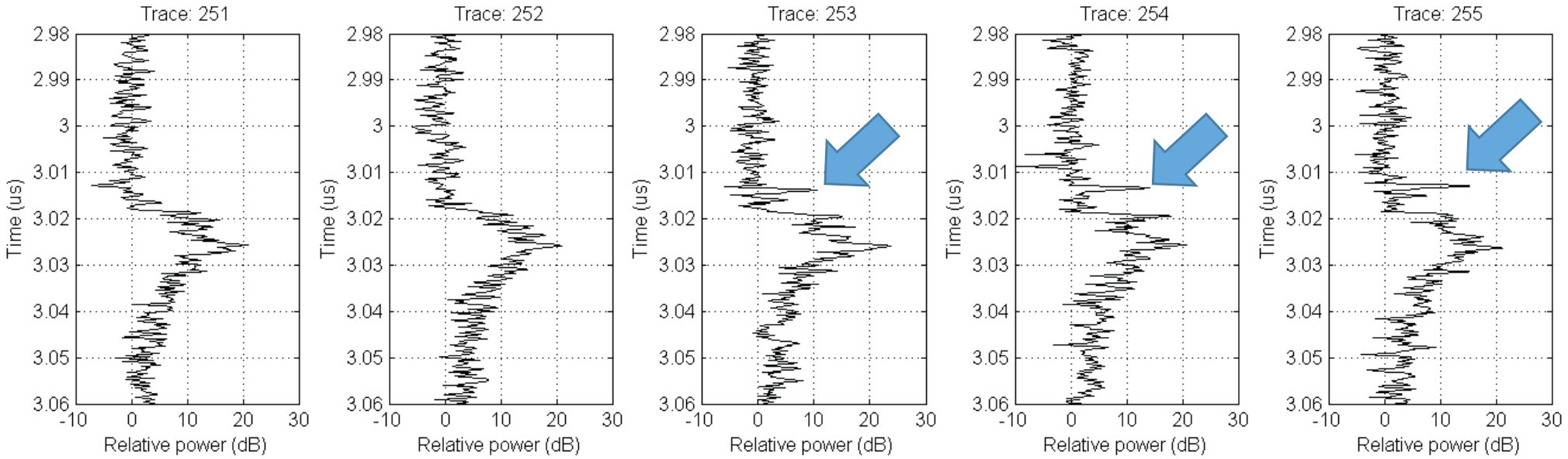

σ = 13.3 cm μ = 39.7 cm
NORD_CAMP_1M_GRID_SSE Year: 2014 Grid: 60 x 50 m (N = 3111 pts)
Frequency
Snow Depth [cm]

# General concerns with in-situ data

- Existing literature of in-situ snow depth measurements lacks thorough discussion of error estimates.
- Literature quotes 1 cm accuracy but errors up to 10 cm have been reported.
- Histograms suggest that magna-probe does not resolve snow-depths < 7-8 cm. True? Bias?
  Similar to minimum thickness that radar can resolve.
- Geolocation errors. GPS is quoted as accurate to within 10 m (realistic).
  A geolocation error of the same order of magnitude as the size of the radar footprints makes exact comparisons difficult.

# Corner reflectors can help with geolocation uncertainty



# Other challenges: pressure ridges

A problem for everyone (in-situ, airborne, modelers)
No EM data, but snow depth.
What do snow depth measurements
over pressure ridges represent?